Real Time Systems
Impact of Network Communications

2015 Propulsion Control and Diagnostics Workshop
NASA Glenn Research Center, November 2016

with

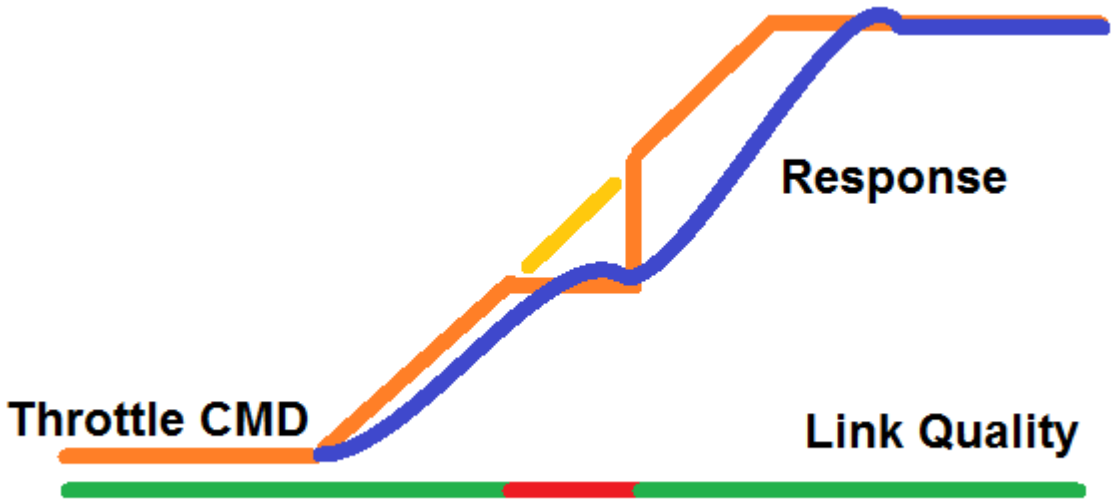
Eliot Aretskin-Hariton and Dennis Culley
Intelligent Control and Autonomy Branch

Overview

- Goals of real-time communication networks
- Centralized vs. distributed systems
- Modeling and simulation efforts at GRC
  - Hardware models of multidrop network
  - Software models of multidrop network
- Exploring critical parameters for digital networks

Goals

- Create network models for system simulation
  - What types of failure modes should we expect
  - How can we simulate these failure modes
  - How can we design control systems to overcome these failure modes

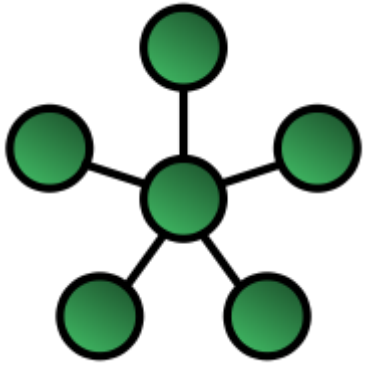


- Derive Network requirements
  - What is the minimum speed the network requires to operate
  - What type of security can be used to ensure command authority

Centralized vs. Distributed

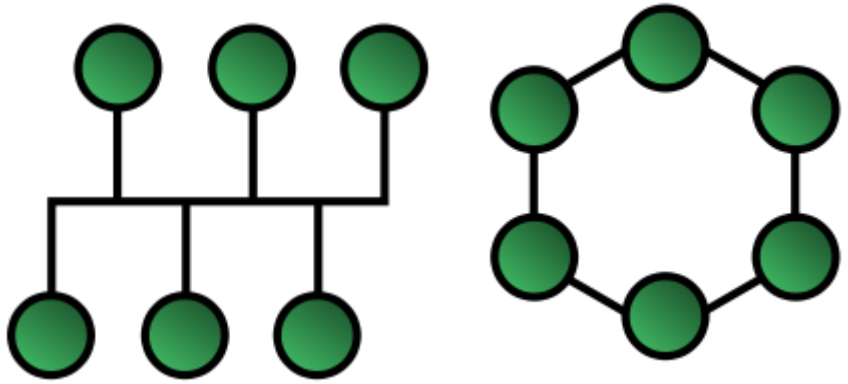
Centralized & Analog

- All data is available instantly
- Dedicated cable for each node
- A/D handled by central node
- Analog sensor/actuator interfaces prevent easy replacement & alternative sourcing of components



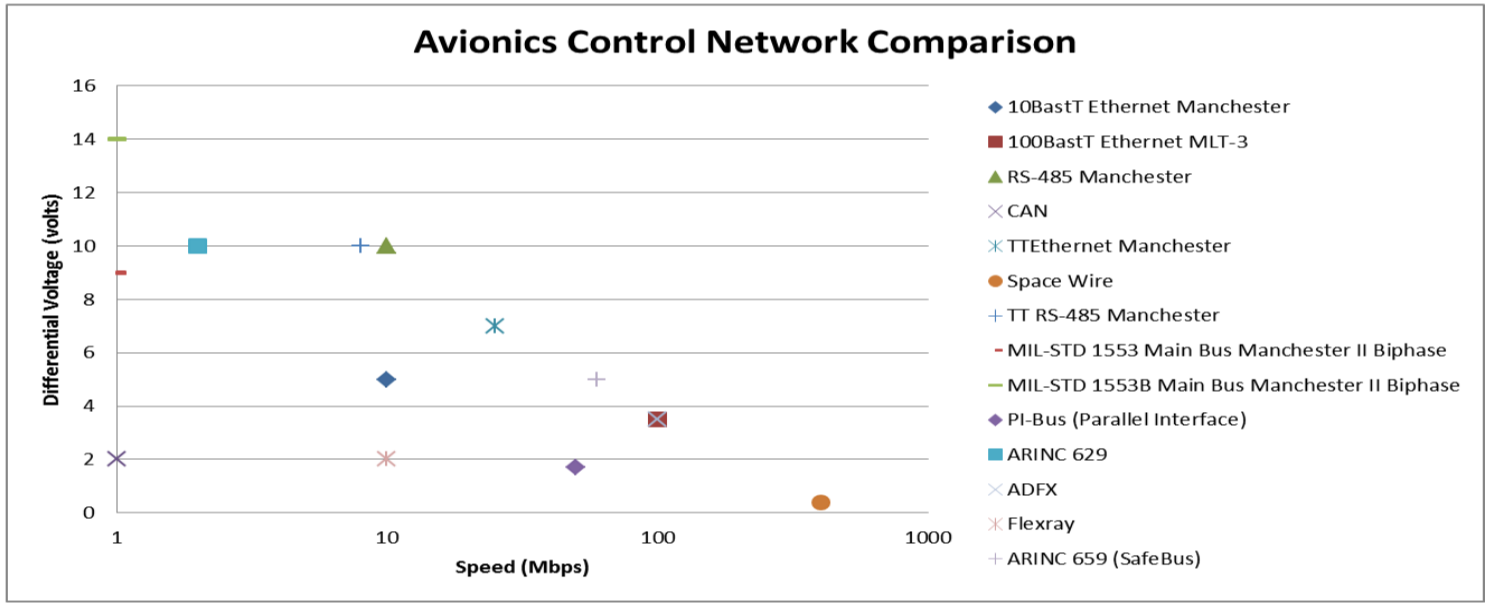
Distributed & Digital

- Data is sampled sequentially
- A/D imbedded in the smart node
- Drop-in component compatibility
- Packet delay
- Packet loss
- Packet corruption

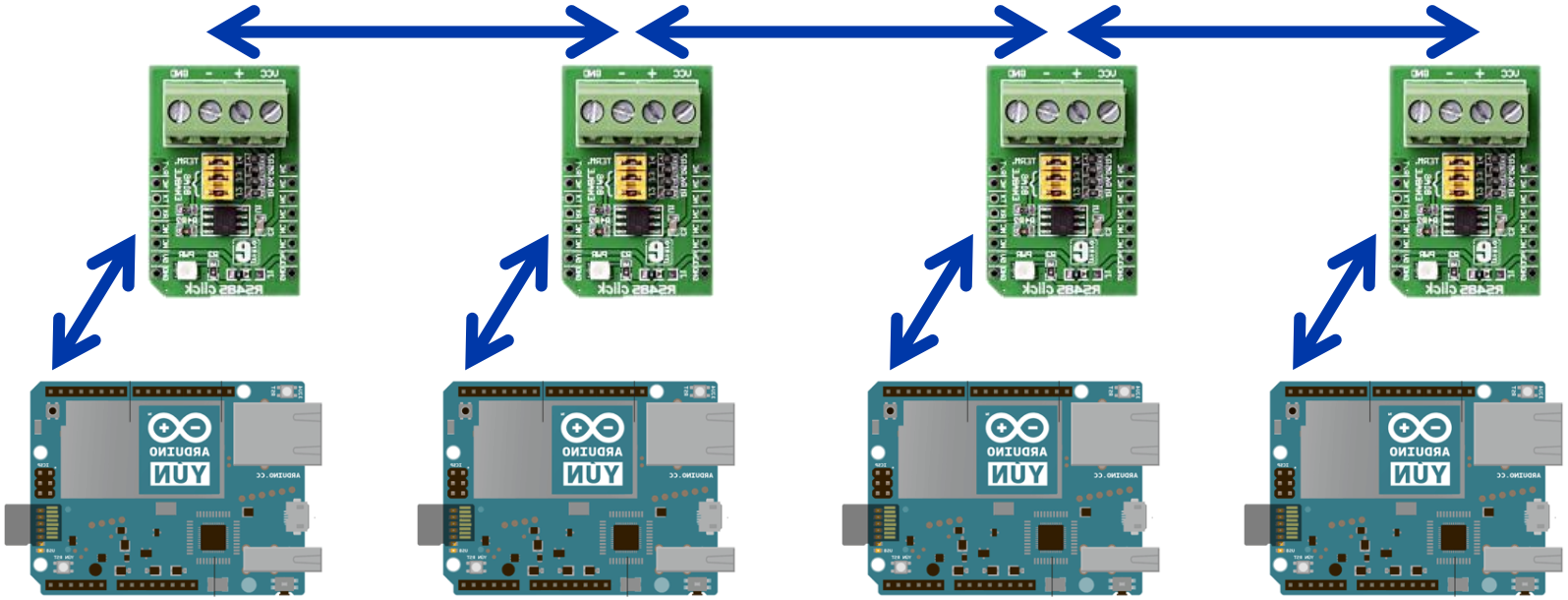


Distributed Network Hardware Simulation

- Data flow is limited by hardware selection
- Final specifications of hardware are not yet complete
- Guidelines specifications that we used when choosing a network:
  - Multi-drop bus with RS-485 hardware,
  - Master / Slave with schedule dictated by master
  - 10Mbps maximum speed
  - 20MHz max clock speed
  - 18 bytes per message
  - Preamble, Data,
  - Break Field, Sync Field
  - CRC-15 Checksum



Empirical Network Model: multi-drop network implemented on an RS-485 physical layer



Node 03
(Actuator)

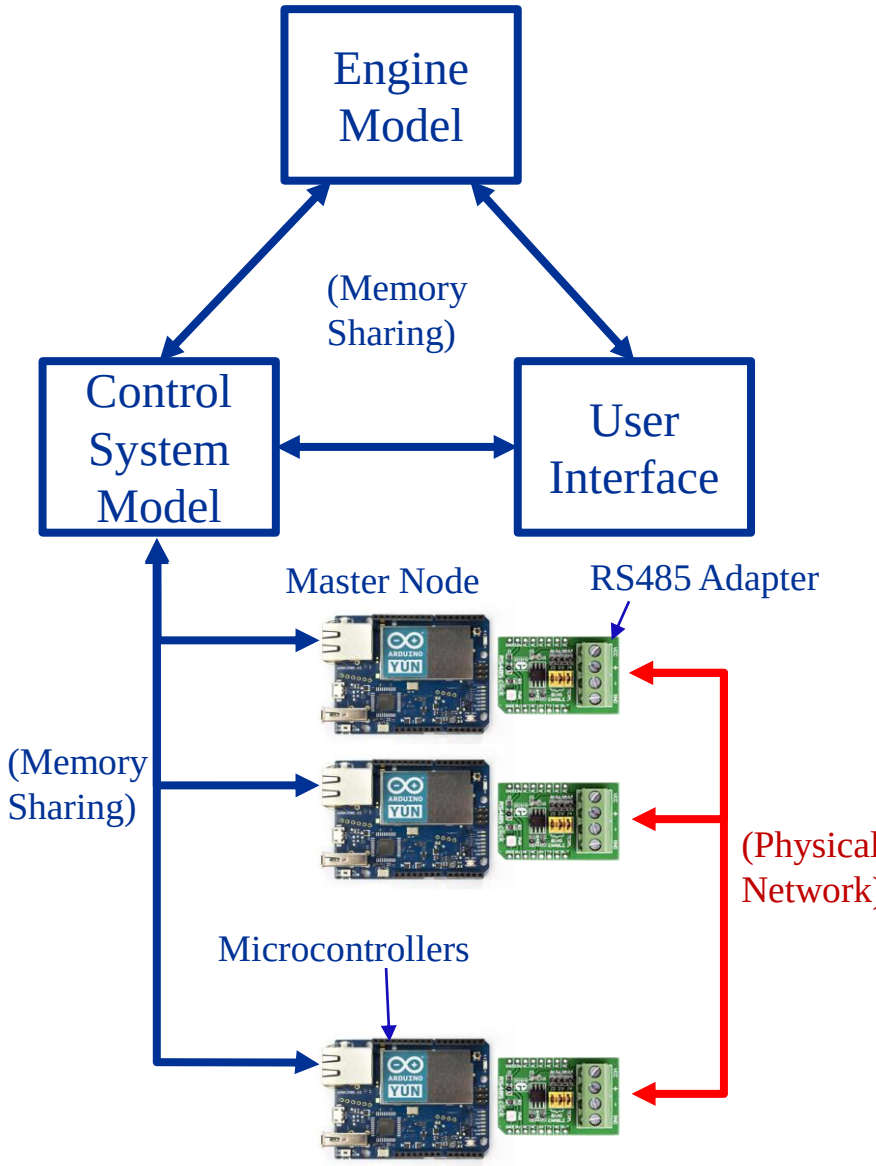
Node 02
(Sensor)

Node 01
(Sensor)

Node 00
(Master)

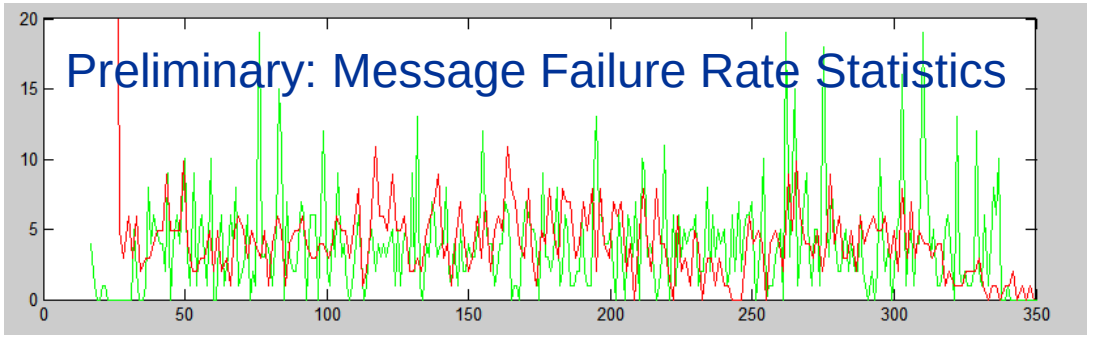
Physically Distributed Control Functions in Simulation

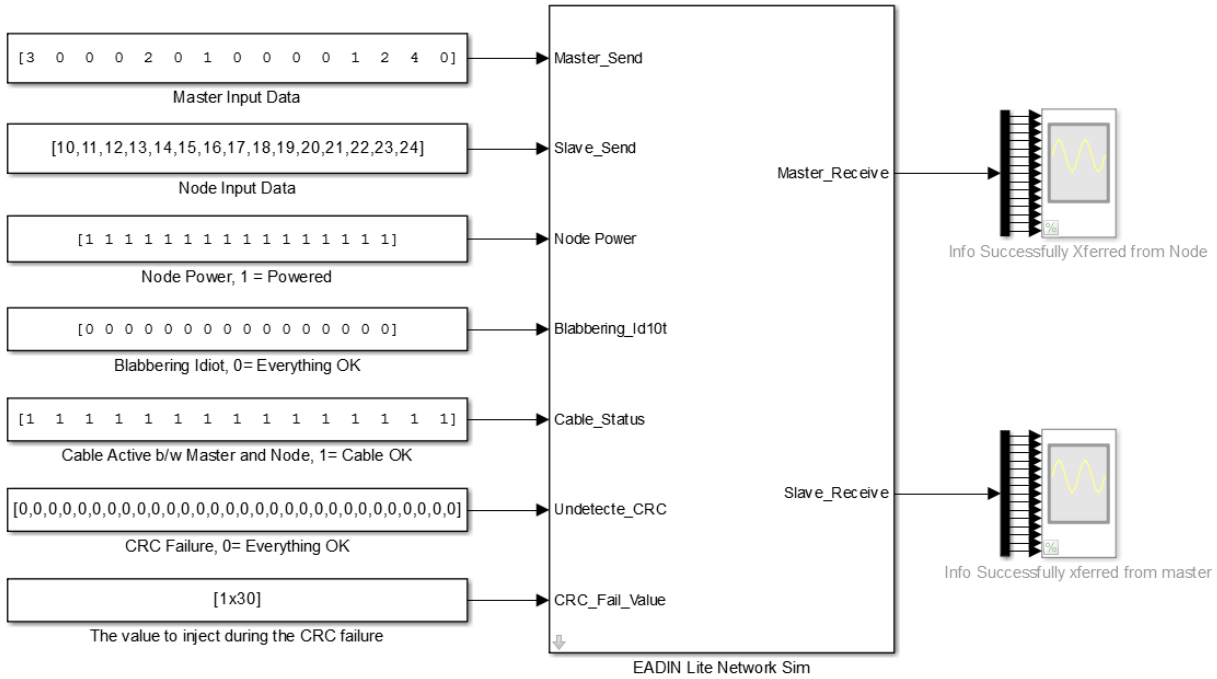
- Smart node simulated in Linux / Python
  - Ported from Simulink
- Communication
  - Implemented in C++
  - Close to real-time processor
  - Predictable command execution time
  - 16MHz
  - Software available on NASA GitHub
  - https://github.com/nasa/EADINLite



Simulink Model of Multidrop Network

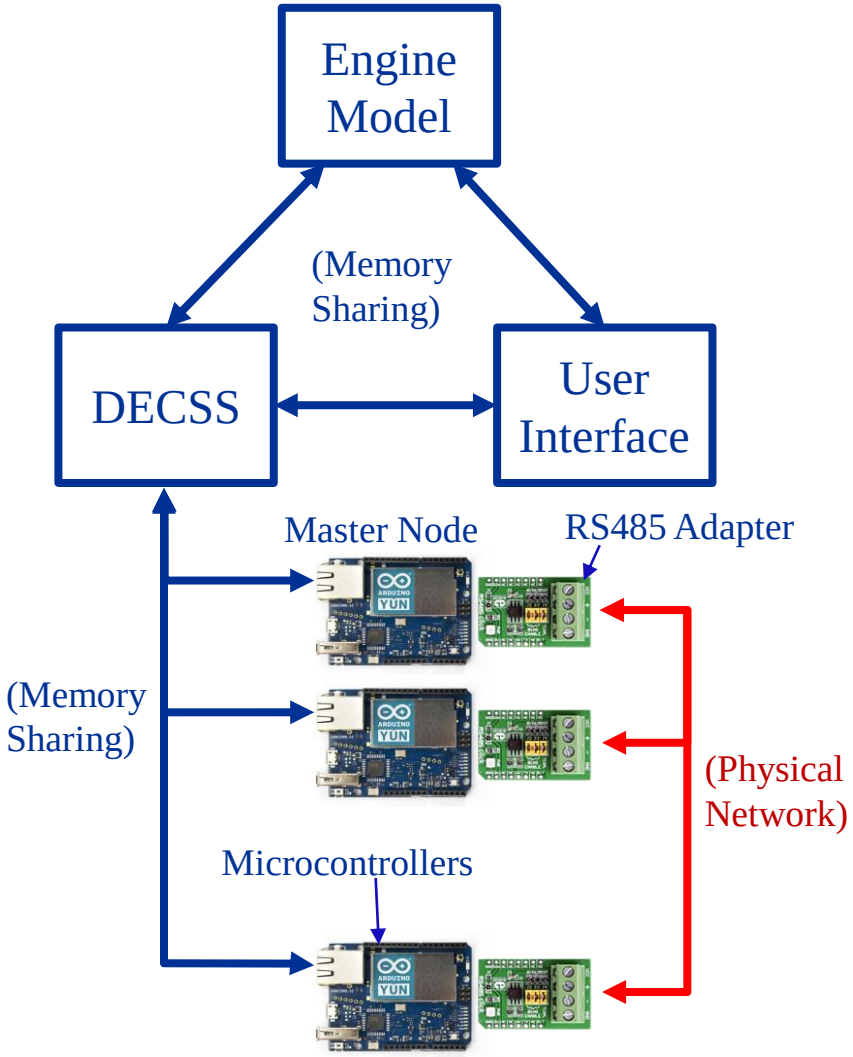
- Simulated failure modes
  - Packet Loss (% or time dependent)
  - Power Loss
  - Cut Cable
  - Blabbering Idiot
  - CRC Failure
- Final results:
  - Did the data arrive at it's destination?
  - Yes/No



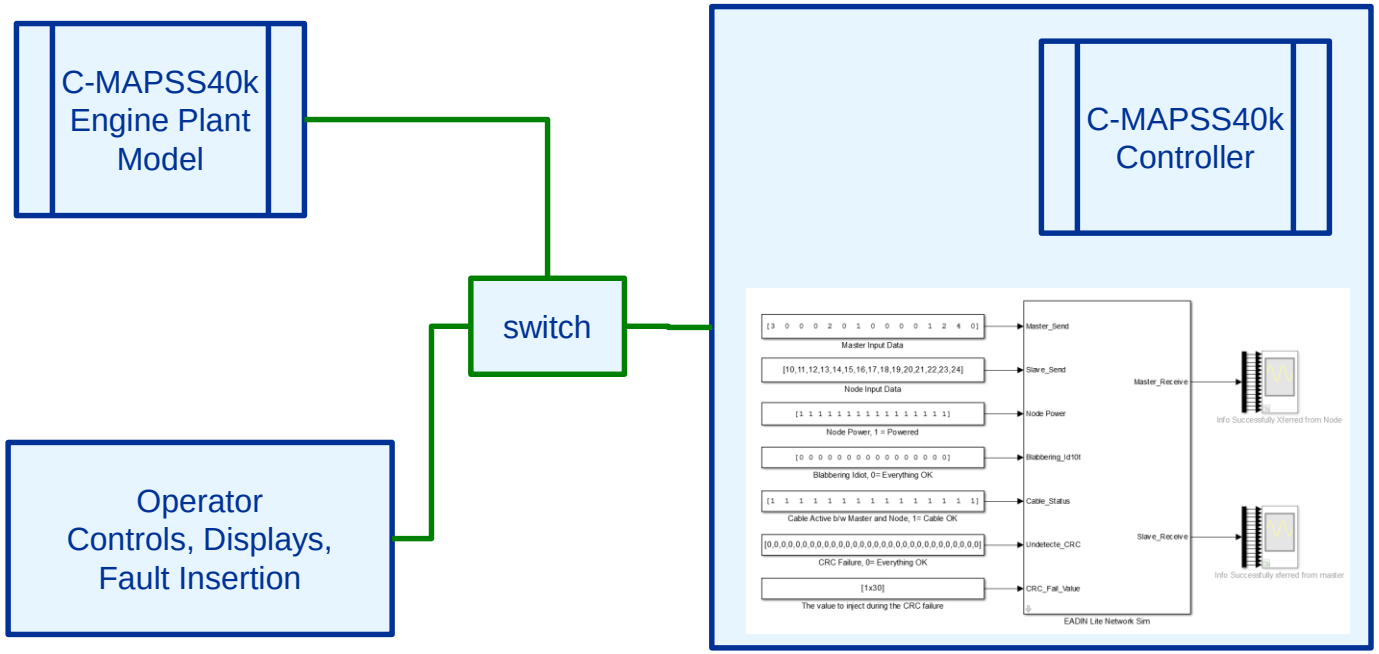


Real Time and Faster than Real Time Testing

- Real-time system

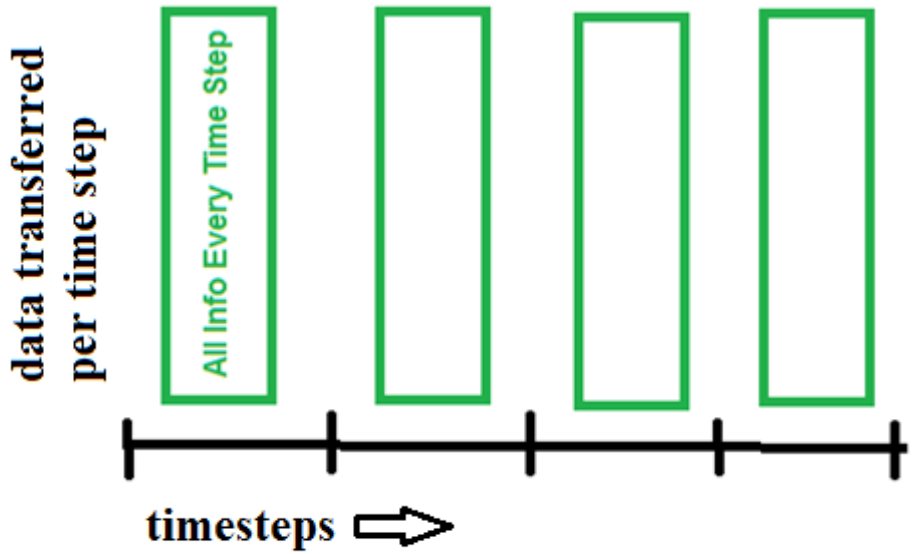


- Faster than real-time system

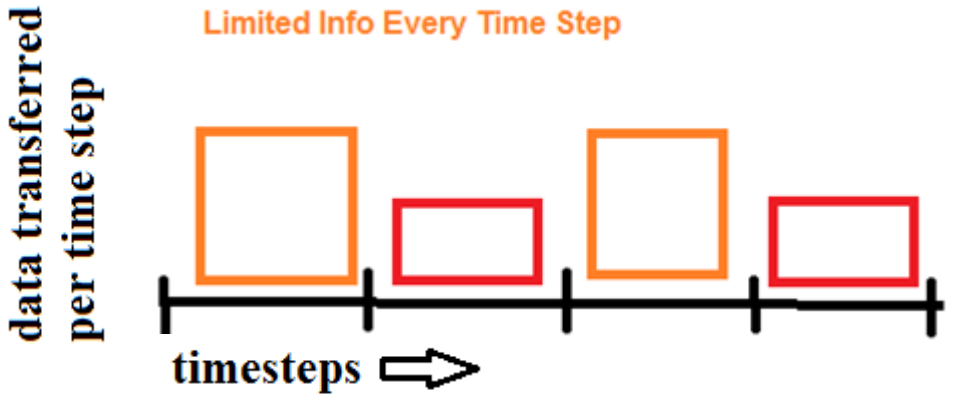


Scheduling and the Impact on Bandwidth

- Analog systems provides the control system all info. at every time step
- Sensors are oversampled

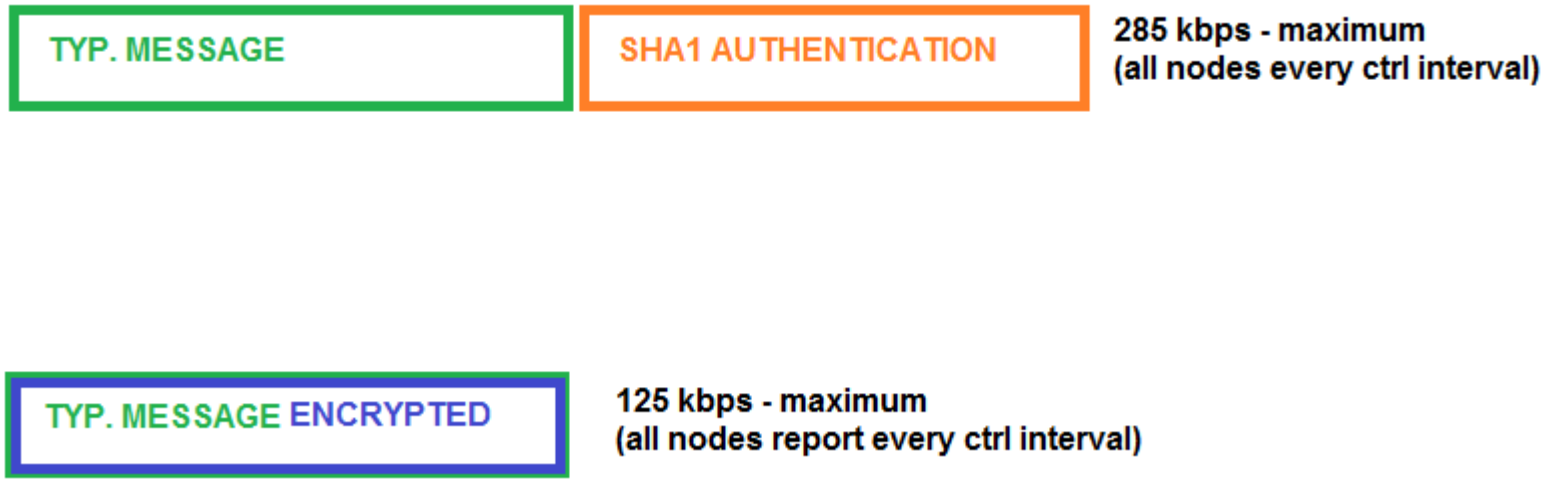


- Digital bandwidth is limited
- Sensors in real systems sample at different rates
- Careful design considerations required to maintaining controllability while minimizing bandwidth



Information Security and the Impact on Bandwidth

- HMAC authentication can significantly increase message size while providing message source authentication
- Authentication protocols are well understood and widely deployed
- Encryption can limit message size increase, but is relatively untested in real-time systems with limited bandwidth and processing power



Minimum Bandwidth Estimates

- CMAPSS40k specific estimates on minimum bandwidth. Each message

- 29 kbps - 18B message, at minimum time constant (3 messages / 15ms)
- 29 kbps - with encryption
- 66 kbps - with SHA1 authentication (+23B/message)

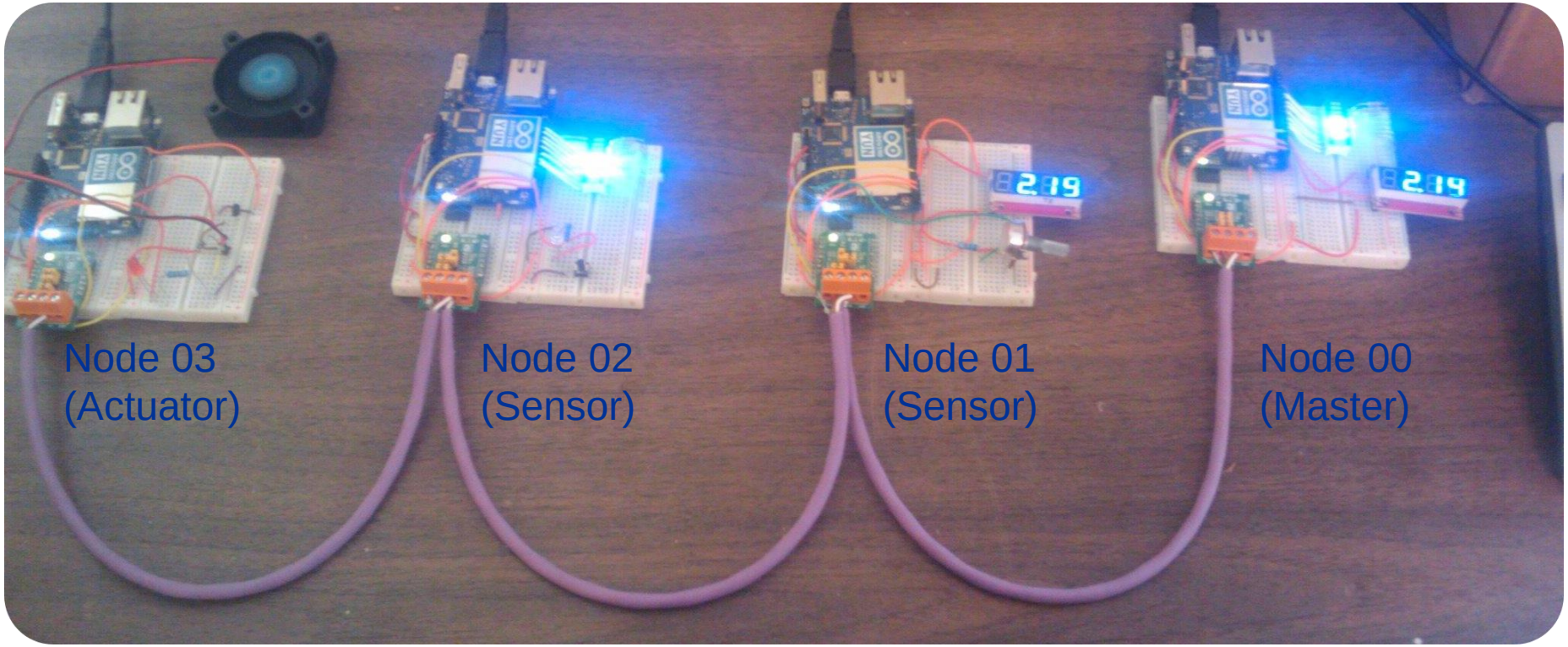
- 285 kbps - 18B message, 13 messages/ 15ms, SHA1 encryption

- Both encryption and SHA1 require more complex FPGA / ASIC design of to be part of the communication system
- SHA1 is a NSA standard HMAC authentication method

Conclusions

- Analog, centralized control systems have access to all information at all times
- Digital, distributed control systems have information availability and synchronization challenges
- Control network modelling allows important exploration of the various limitations imposed by including a network in a control system
- Empirical methods were used to analyze the data flow in multi-drop networks for the purpose of developing models for simulation
- Additional concerns about data integrity and authentication will impact resource utilization
- The network models will be used to explore control system design space and build recommendations on network requirements

Questions?


Node 03
(Actuator)
Node 02
(Sensor)
Node 01
(Sensor)
Node 00
(Master)